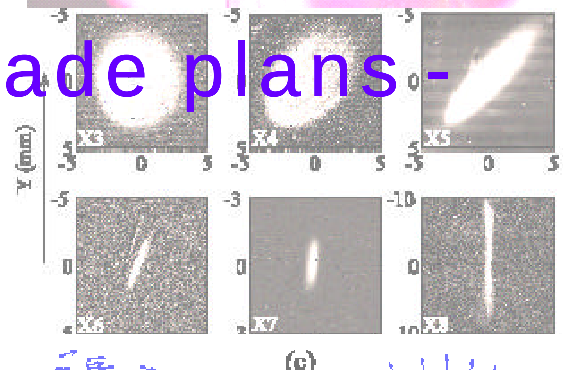
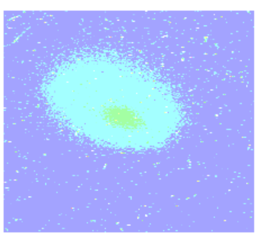
FNPL: injector test stand for ILC & advanced accelerator R&D

- Program and upgrade plans -



Philippe Piot

Fermi/NICADD Photoinjector Laboratory



http://nicadd.niu.edu/fnpl

Outline

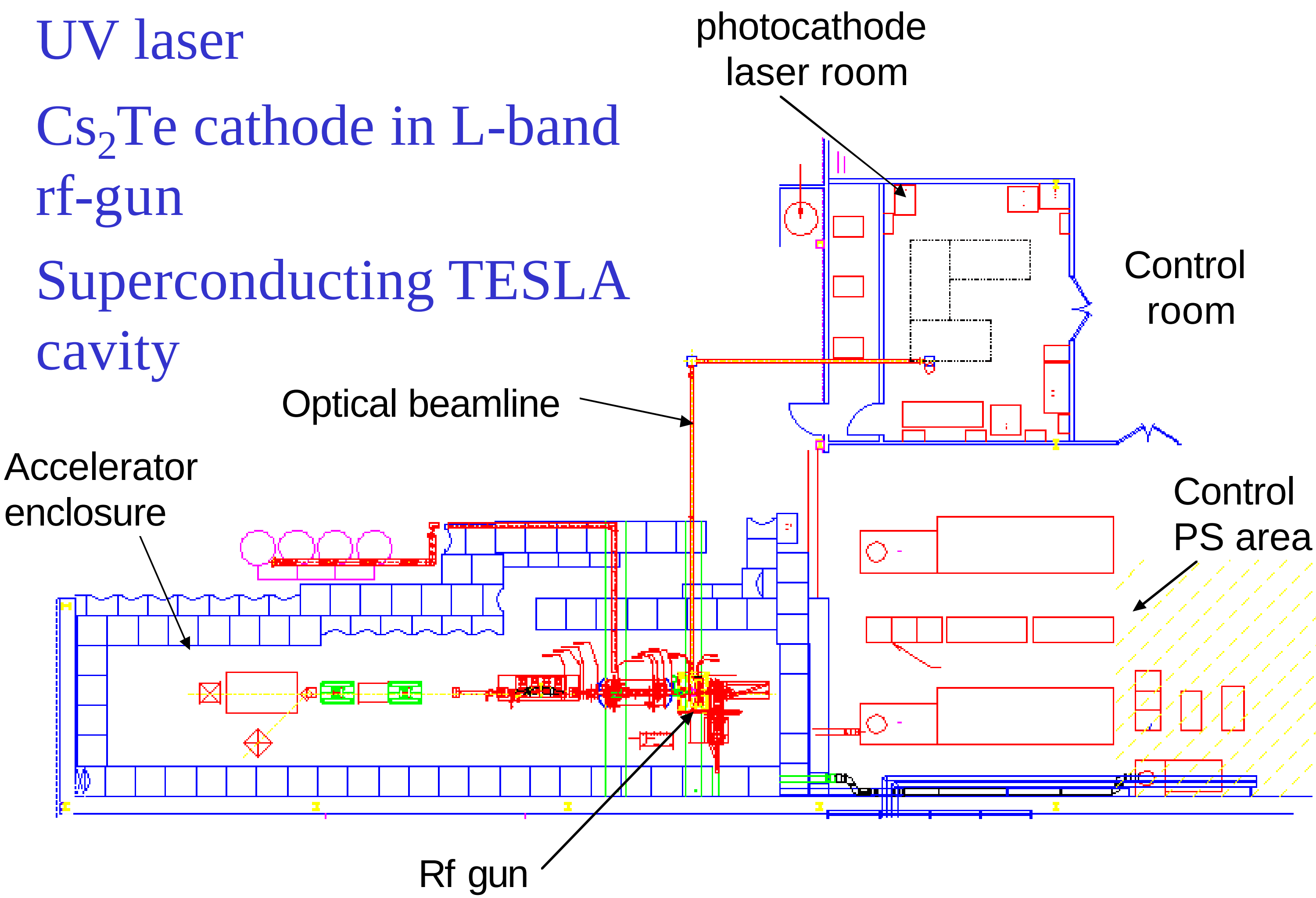
- Introduction
- Present activities:
  - ILC-related studies
  - Advanced accelerator R&D
- Upgrade plans
  - FNPL energy upgrade @ A0
  - SMTF injector
- Conclusions & plans

Introduction

- 2 Injectors built in early 90's by FNAL/DESY with contributions from IN_2P_3 (Orsay), INFN (Milano), UCLA, …
- 1 installed in at DESY TTF-1 (1^{st} POP for UV SASE-FEL)
- 1 installed at FNAL in A0 building: FNPL
- FNPL is used for beam physics and advanced accelerator R&D
- FNPL is foreseen to serve as an e- injector for SMTF

Overview of FNPL infrastructure

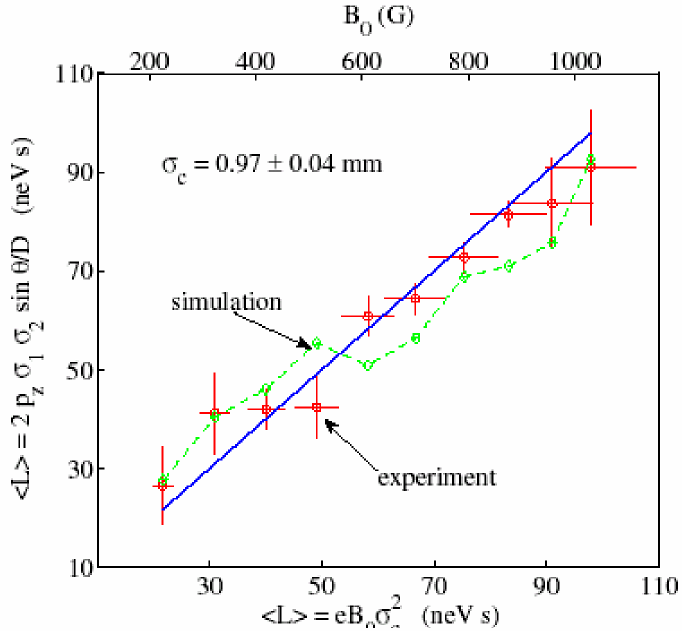
- UV laser
- Cs_2Te cathode in L-band rf-gun
- Superconducting TESLA cavity

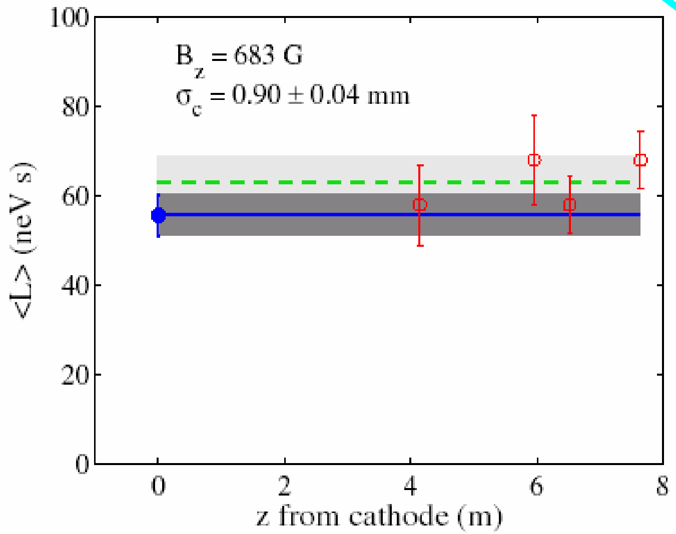


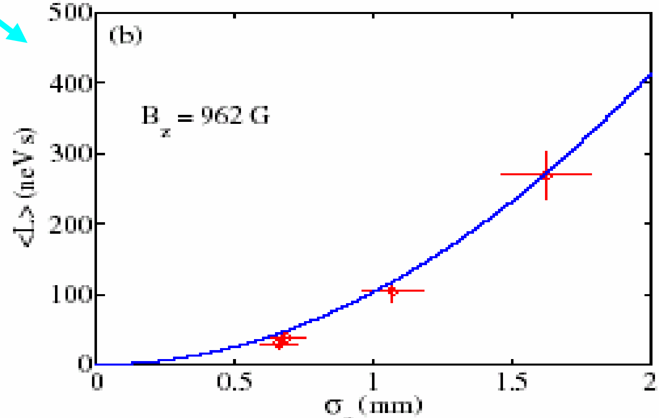
Angular-momentum-dominated beams

- Photoinjector production of AM-dominated beam for e- cooling, flat beam production
- Check scaling law:

$$\langle L \rangle = eB\sigma_c^2$$

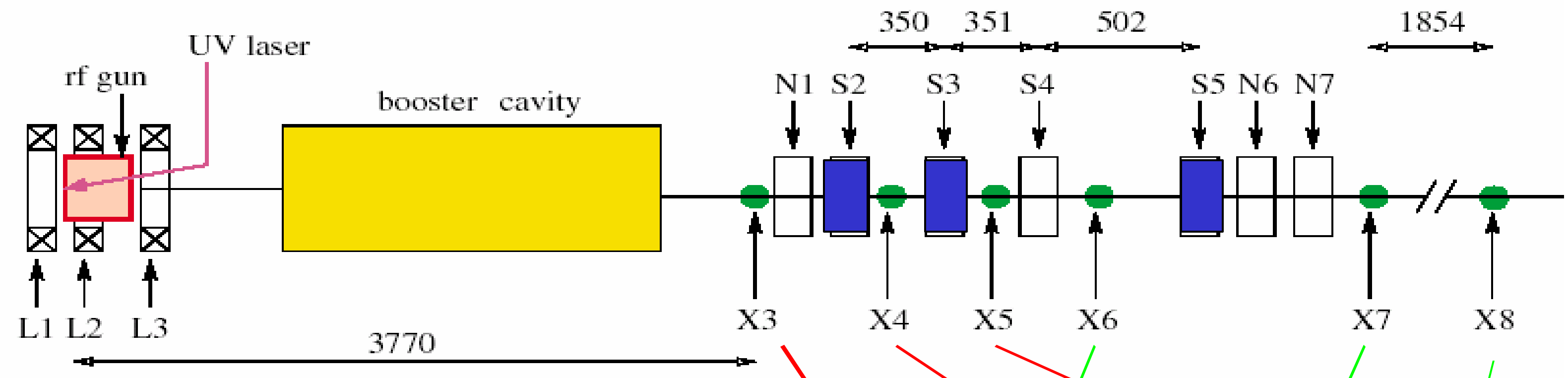




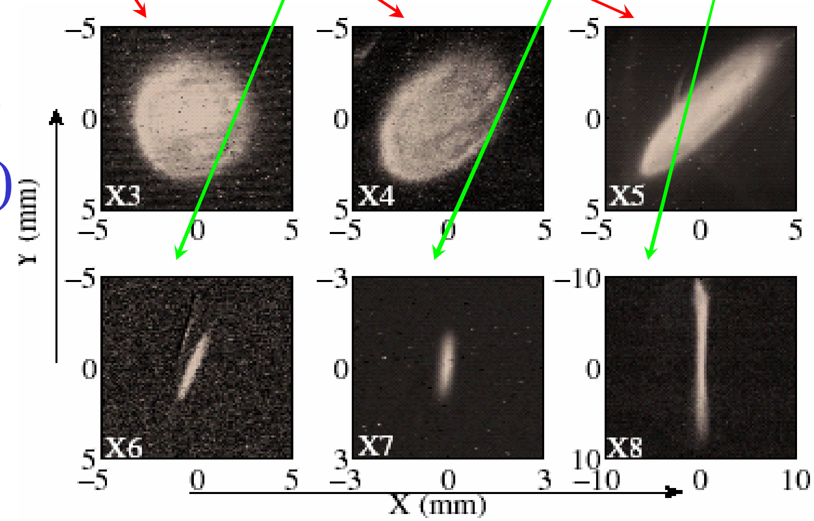


Y.-E Sun et al. (U. of Chicago / FNAL /Berkeley)

Production of flat beams

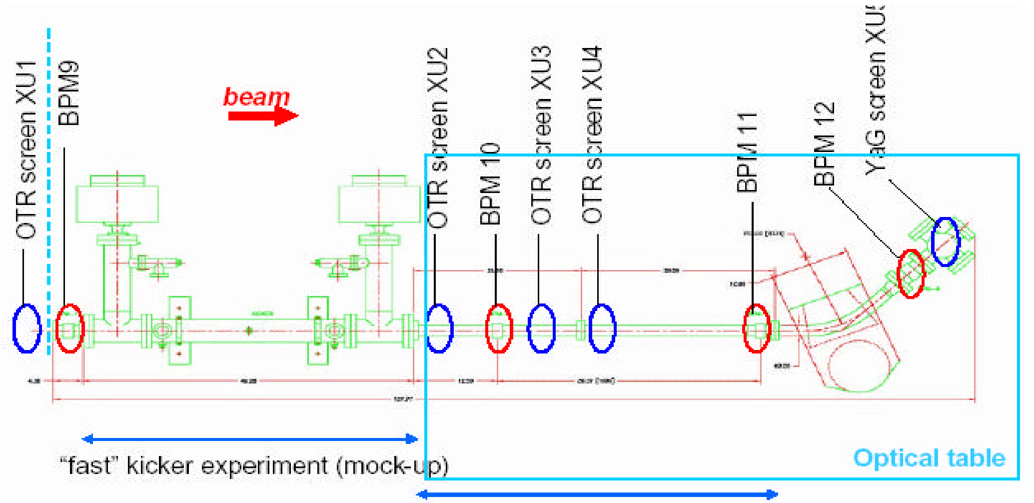


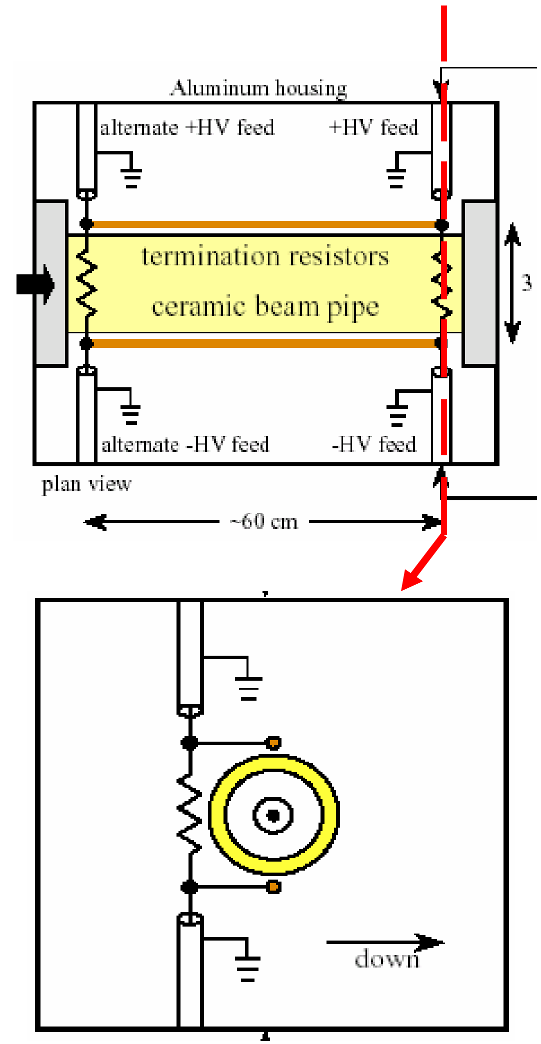
- Use a 3 skew quadrupoles
  ⇨ torque ⇨ removes L_z
- 1st POP in 99 **(D. Edwards et al)**
- Feb 2005, achieved (95% rms)
  $e_x / e_y = 100\pm5$ (=41/0.41)
- Further optimizations with new photocathode drive laser (using stacked pulses)



Y.-E Sun et al. (U. of Chicago / FNAL/Berkeley)

Fast-kicker tests for ILC damping ring



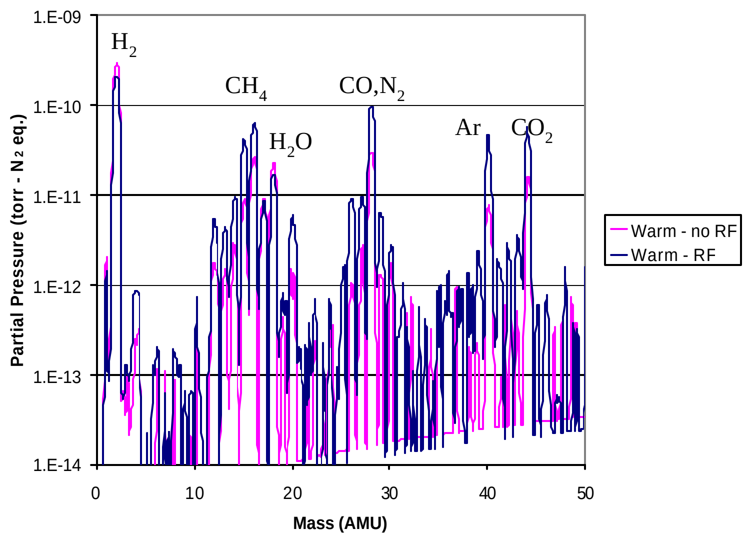


- R&D on fast kicker aimed to shorten ILC damping ring
- Beam-based measurement of kick rising time will be done at FNPL
- Summer 2005 (installed): mockup experiment using transmission-line kicker ⇨ test of pulser + measurement methods
- In 2006 ?: install a prototype fast kicker

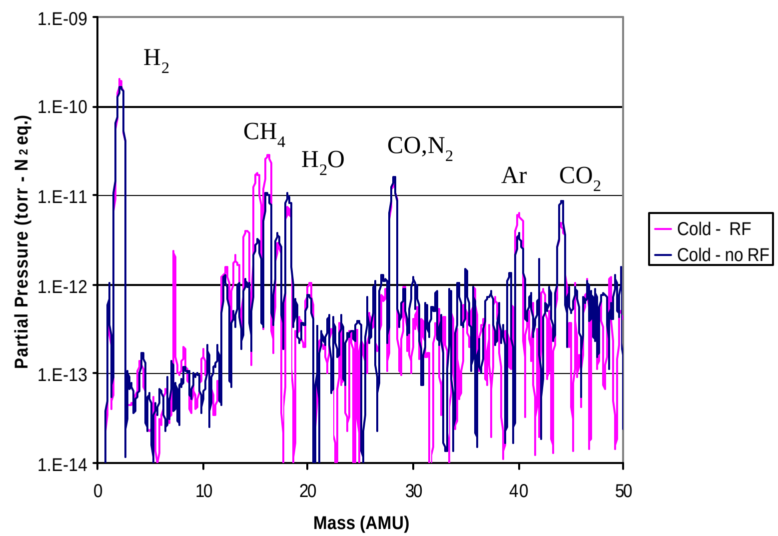
G. Gollin et al. (UI @ Urbana Champaign + FNAL + Cornell)

R&D toward polarized e- source for ILC

- Polarized e- ⇨ operation GaAs cathode in rf-gun
- GaAs requires P~10^{-12} Torr in DC guns
- N_2-Cooled NC rf-gun ⇨ lower equilibrium pressure



An RGA spectrum with and without RF in a room temperature gun. All of the gases in the system, save hydrogen, are outgassed when RF is applied to the gun.

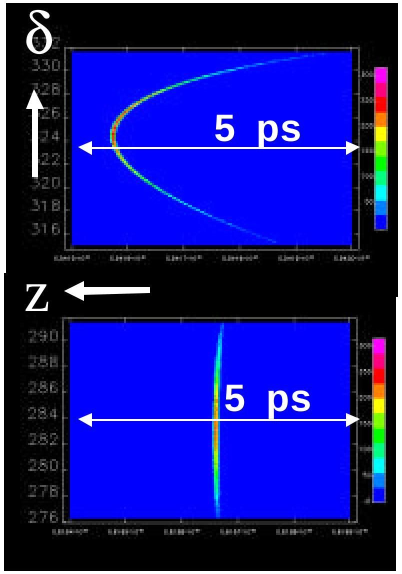


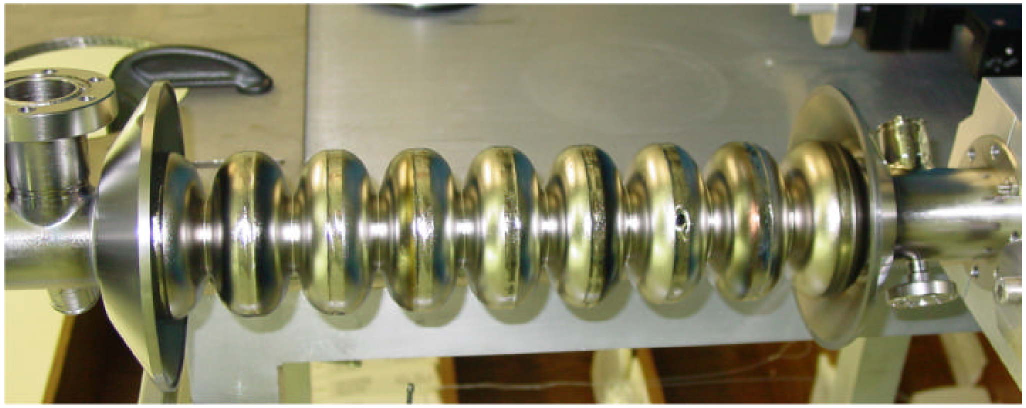
An RGA spectrum with and without RF in a gun cooled to 92 K with liquid Nitrogen. Only methane and argon noticeably increase with RF applied.

R. Fliller III, (FNAL); SBIR with AES

R&D on 3.9 GHz accelerating mode cavity

- SCRF TM_{010} mode 9-cell cavity developed for linearization of (*z*,*d*)
- Applications to many project: FEL-drivers operating at 1.3 GHz, post damping ring BC for ILC

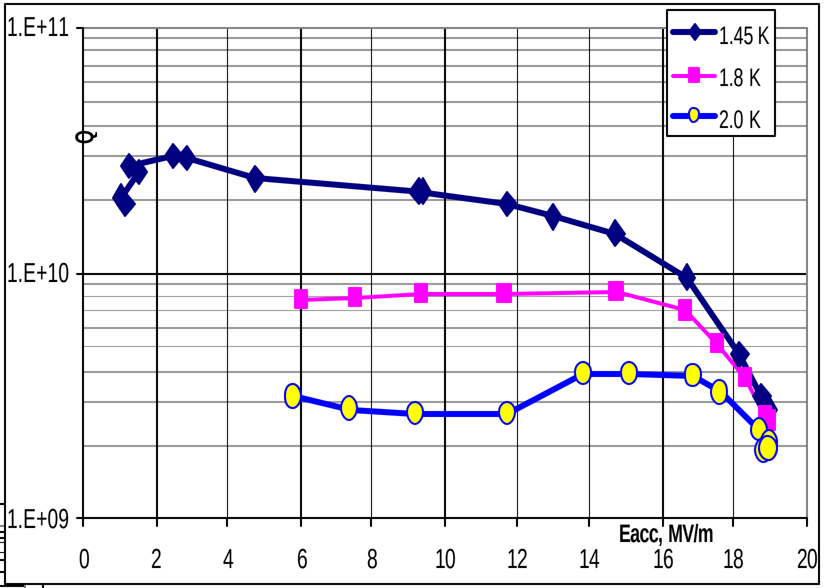


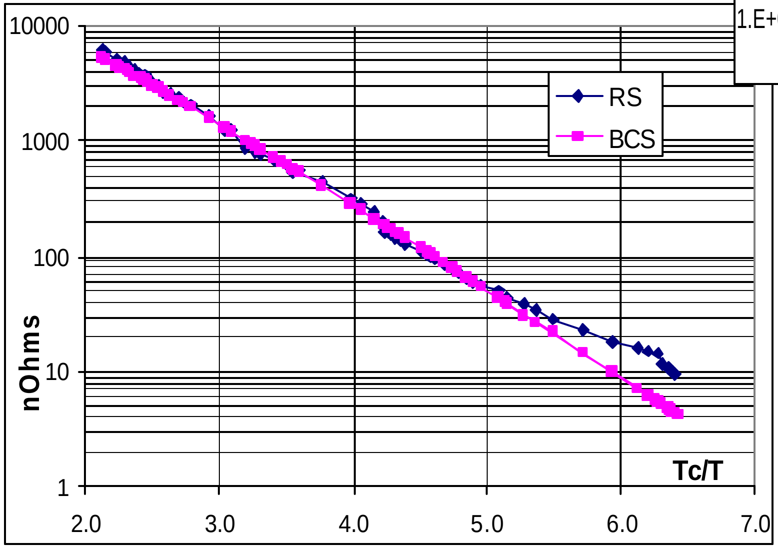


First 9-cell cavity built at FNAL (goal: +4 in 2005)

R&D on 3.9 GHz accelerating mode cavity

- Final cavity preparation done at FNAL (BCP, HPWR)
- Residual resistance Rres 6nW
- Achieved H=103 mT, Eac=19MV/m





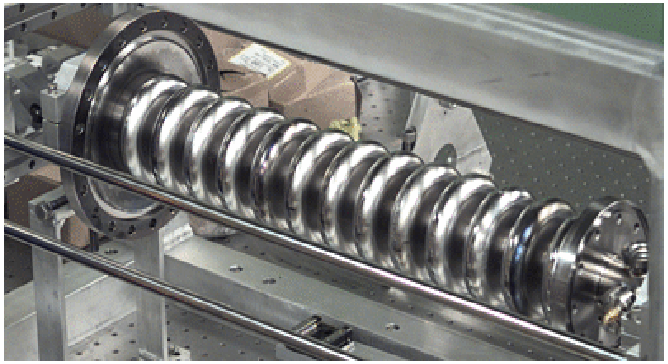
- No field emission
- Maximum acc. Field does not depends on Temp.
- Q=8*109 at Eacc=15 MV/m

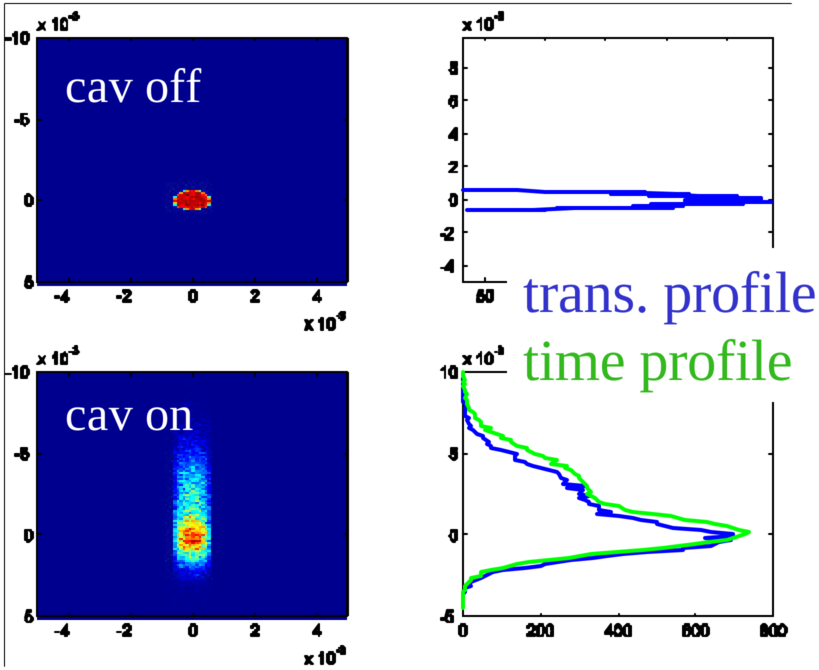
H = 103 mT ⇨
9-cell/3.9GHz: → E_{acc} = *21 MV/m*
TESLA: → E_{acc} = *24 MV/m*

N. Solyak et al. (FNAL)

R&D on 3.9 GHz Deflecting cavity

- SCRF TM_{110} mode (13-cell) cavity initially developed for CKM exp.
- Can be used as bunch length diagnostics
- Crab cavity for ILC
- Longitudinal-to-transverse emittance exchanger

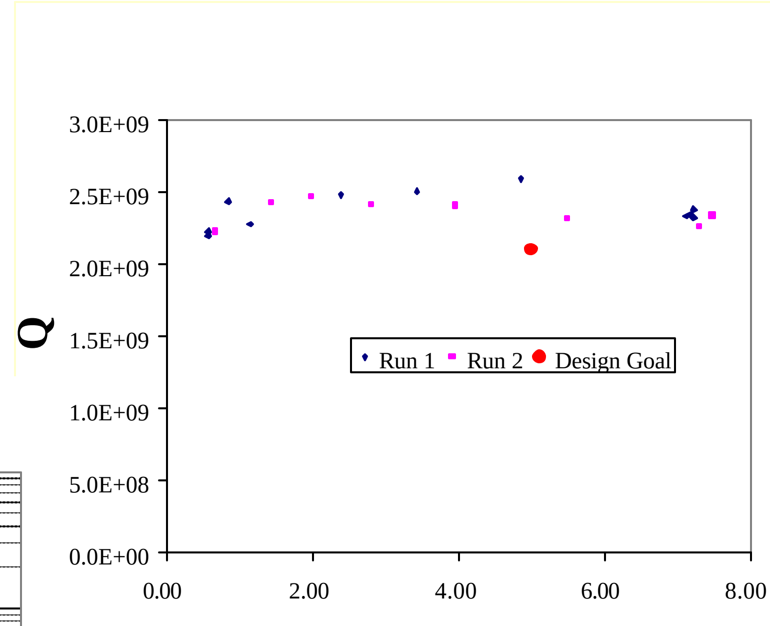




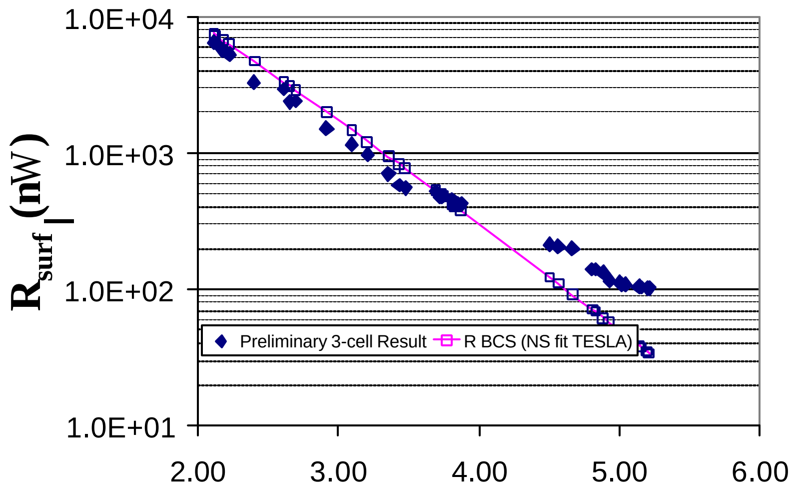
Beam simulation with modeled 13-cell EM fields showing bunch length measurement at the FNPL upgrade

R&D on 3.9 GHz Deflecting cavity

- 3-cell prototype of the deflecting cavity perform beyond specs

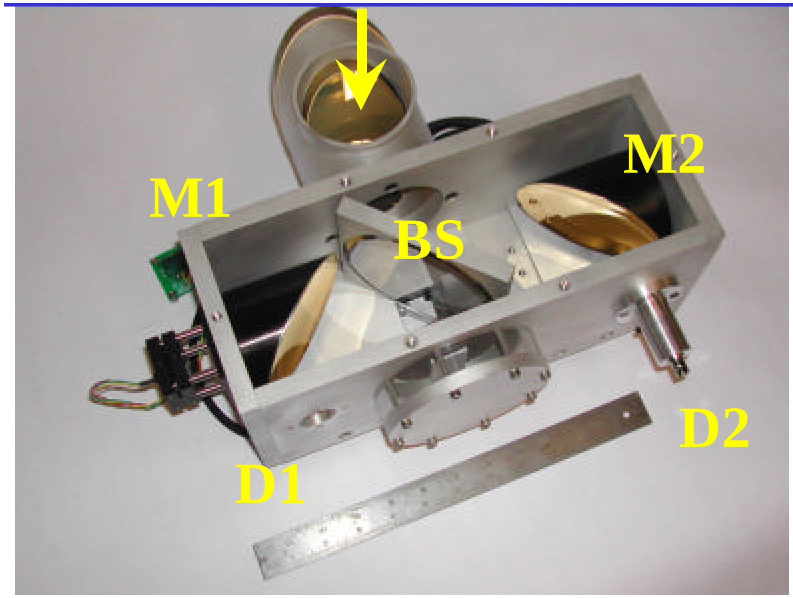


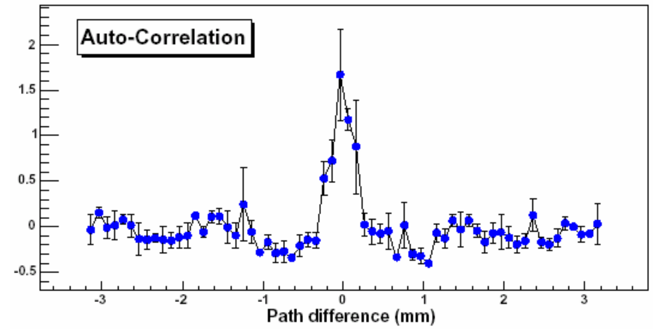
$eV_\perp$ (MV/m)

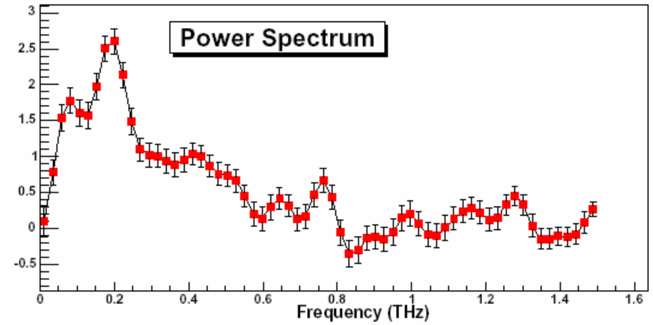


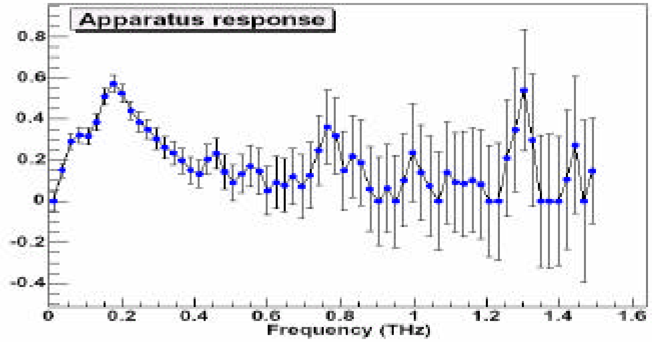
L. Bellantoni, et al. (FNAL/U. of Rutgers)

Bunch-length diagnostics with coherent radiation









- CTR autocorrelation

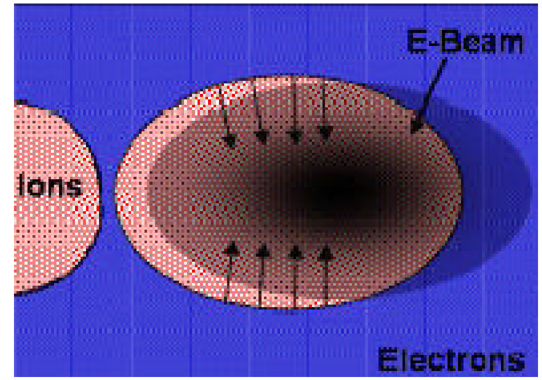
$$\frac{d^2W}{dwd\Omega} \propto \left[N + N(N-1)|\Lambda(w)|^2\right]$$

- Many limitations for sub-mm bunch (FIR detectors, diffraction, …) being investigated at FNPL

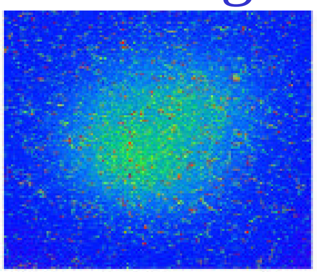
D. Mihalcea U. Happek et al. (NIU & U. of Georgia)

Plasma focusing in under-dense regime

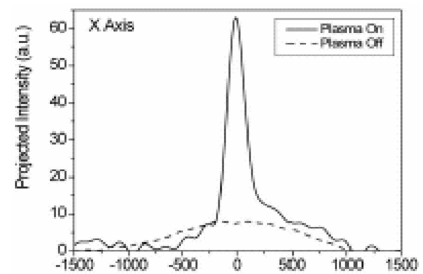
- Uses electrostatic forces to focus beam in both directions
- $B' = \dfrac{en_p}{2e_0 c} \approx 3\times10^{-11} n_p$ [T/m]

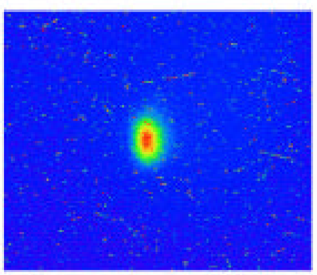


- De-magnified by a factor 22

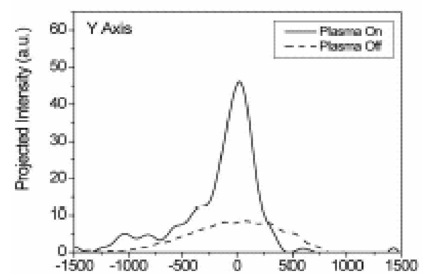


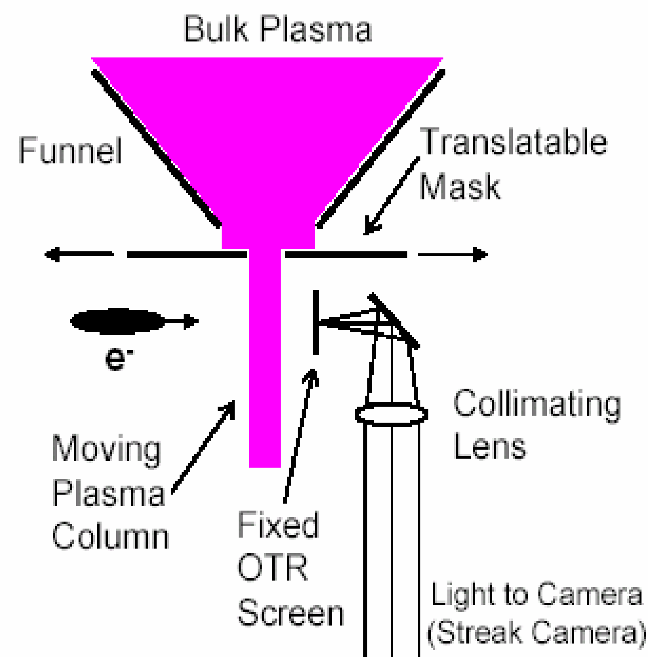
Unfocused - 5 electron pulses





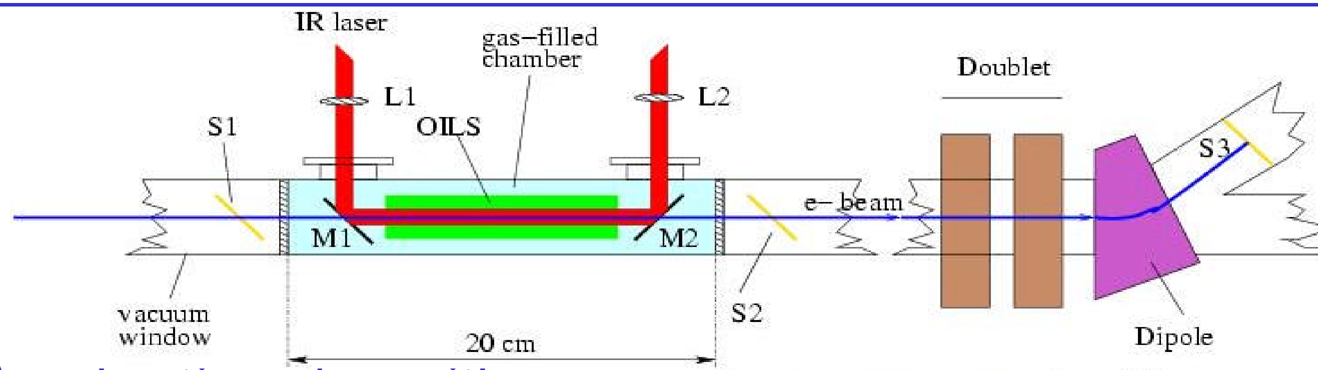
Focused - 1 electron pulse



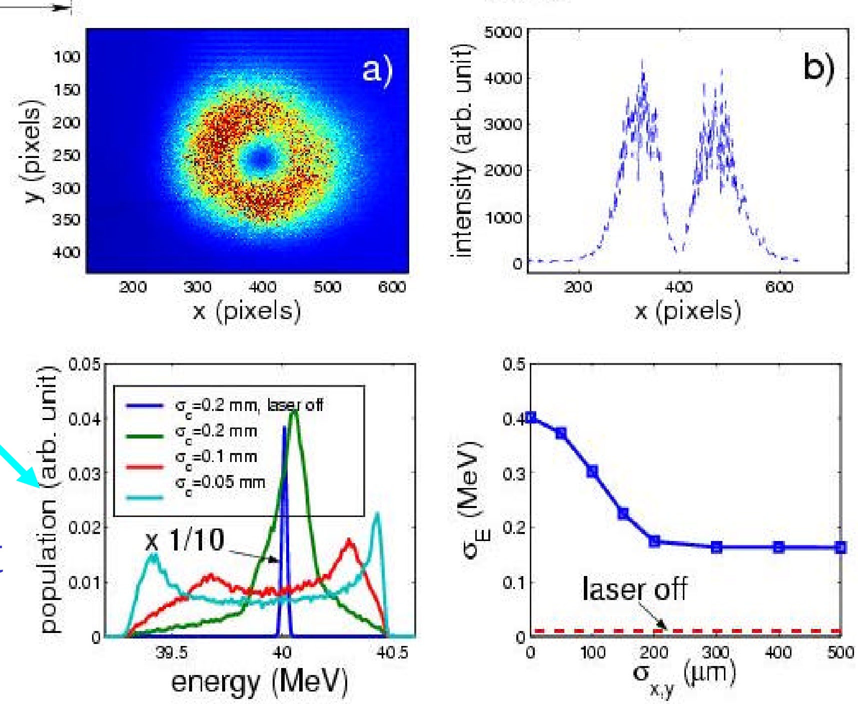


M. Thompson et al. (UCLA)

Inverse Cerenkov acceleration (ICA)



- Acceleration of e- with a radially polarized laser
- Produced TM^*_{01} mode
- investigated experiment feasibility at E=40 MeV
- ICA will produce micro-bunched beam at 1 μm
  ⇨ possible use of these short pulses in other experiment
- **Need 40-50 MeV e- beam!**



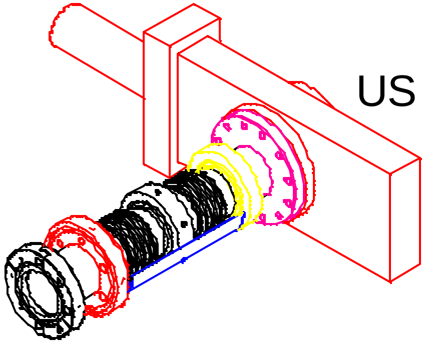
R. Tikhoplav et al. (U. of Rochester / FNAL)

Upgrade plans for FNPL

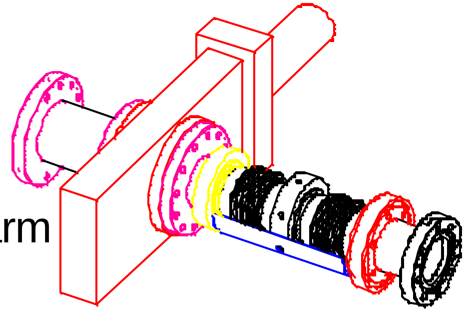
- Main motivation for upgrade: higher energy; beam more rigid + less subject to space charge forces $O(\gamma^{-2})$~*1/10*
- In the upgrade process some problems with the present beamline will be addressed (e.g. bunch compression)
- Recycle present beamline
- Staged upgrade:
  - Early Jan 2006: install 2nd cavity + new downstream beamline that still fits in the present A0 bunker (FNPL upgrade @ A0)
    ⇨ possible test with beam of 3.9 GHz cavities
    ⇨ beam physics
  - In SMTF building: re-optimize injector for ILC parameters integrate the two 3.9 GHz cavities in the injector design
    ⇨ provide a 40-50 MeV e- injector for SMTF
    ⇨ continue beam physics and adv. acc. R&D
  - In parallel: continue upgrading the photocathode drive-laser and develop a cylindrical-symmetric rf-gun

Upgrade plans for FNPL: cavity 2

- Nov. 2004, DESY sent to FNAL TTF-1 booster cav.
- Goal: replace 12 MV/m cav with 25 MV/m cav.
- Since Nov. 2004 FNAL+DESY work on its upgrade
- Retrofitting TESLA type I (12 MV/m) cryovessel for type III (25 MV/m)



US cold-to-warm transition

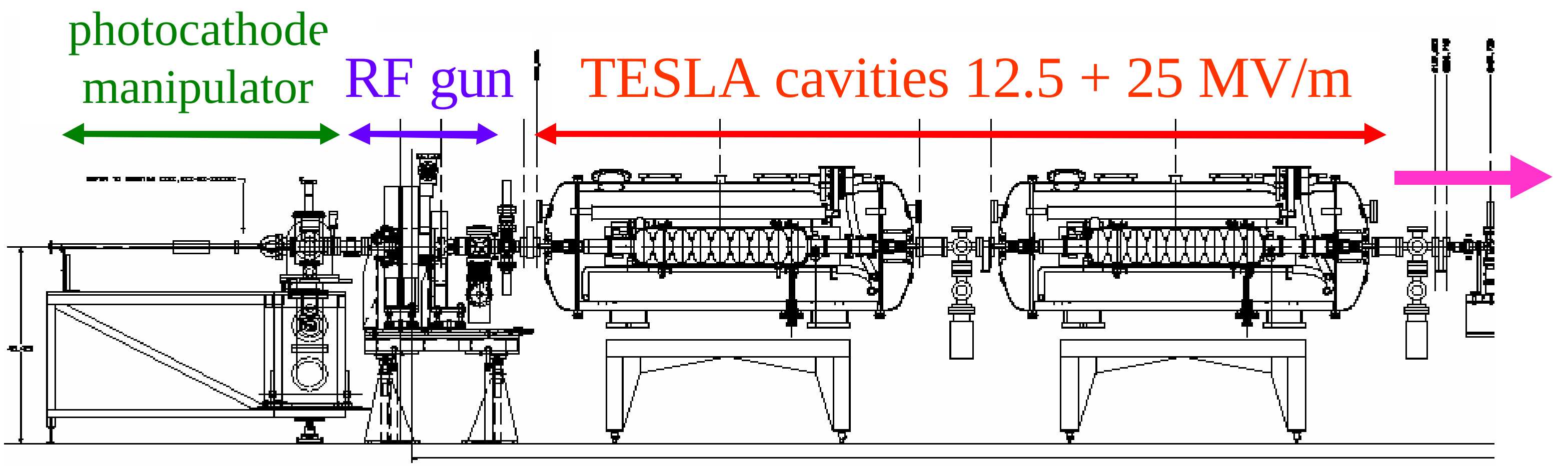


DS cold-to-warm transition

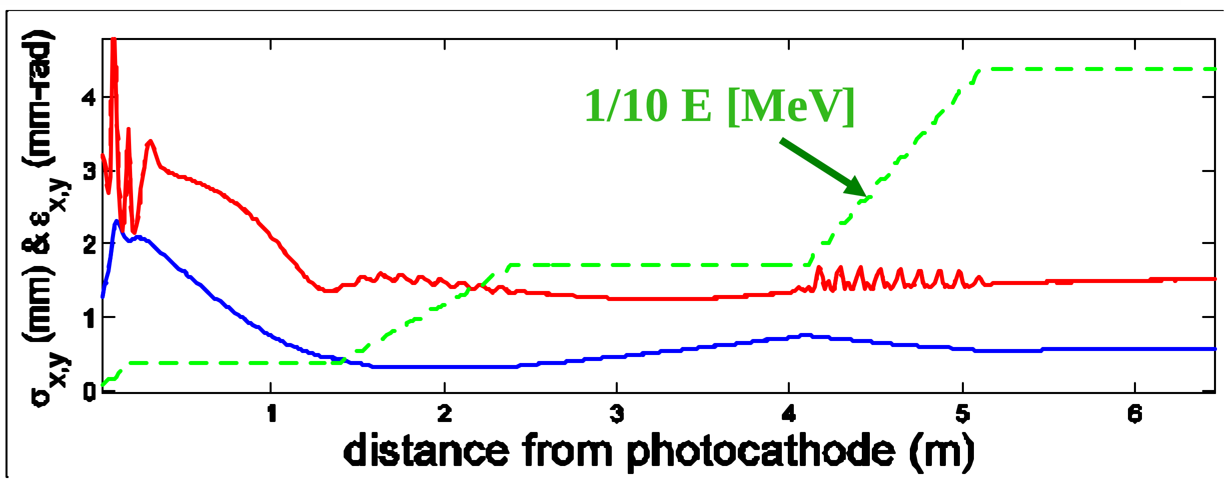
T. Koeth et al. (Rutgers Univ. / FNAL)

Overview of FNPL upgrade @ A0

- Generation and acceleration section

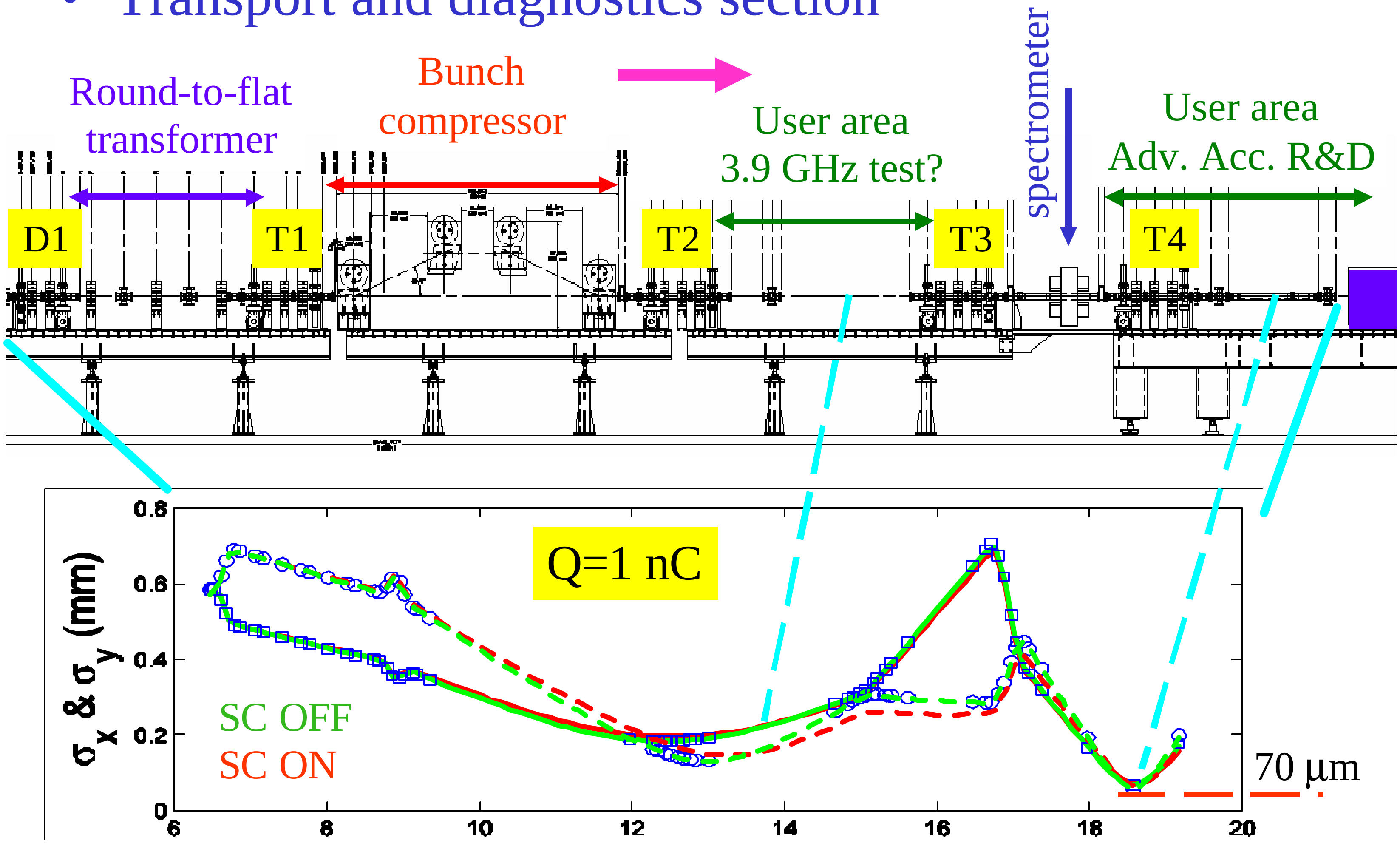


Q=1 nC



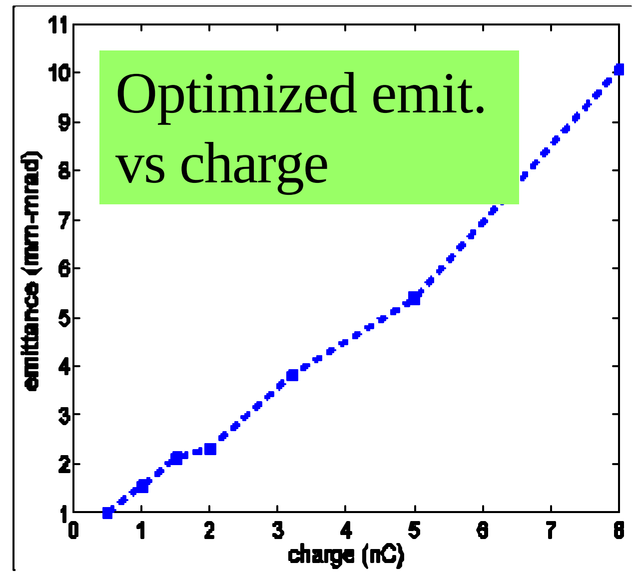
Overview of FNPL upgrade @ A0

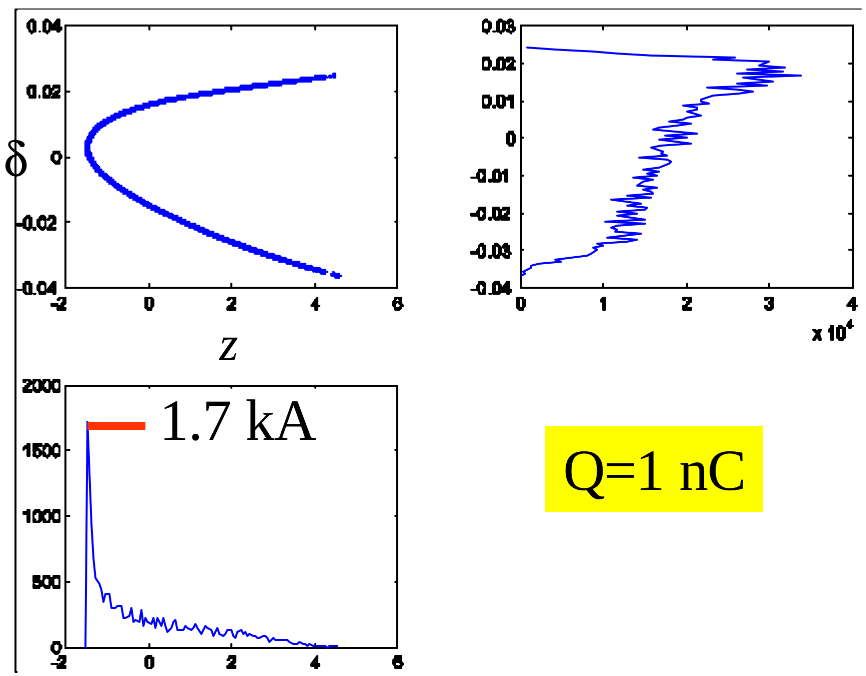
- Transport and diagnostics section



FNPL upgrade @ A0: ILC parameters

- Generation of 3.2 nC with $\gamma\varepsilon <$ 5 mm-mrad possible
- Bunch compression ⇨ high $\hat{I}$ ⇨ wakefield, HOM studies





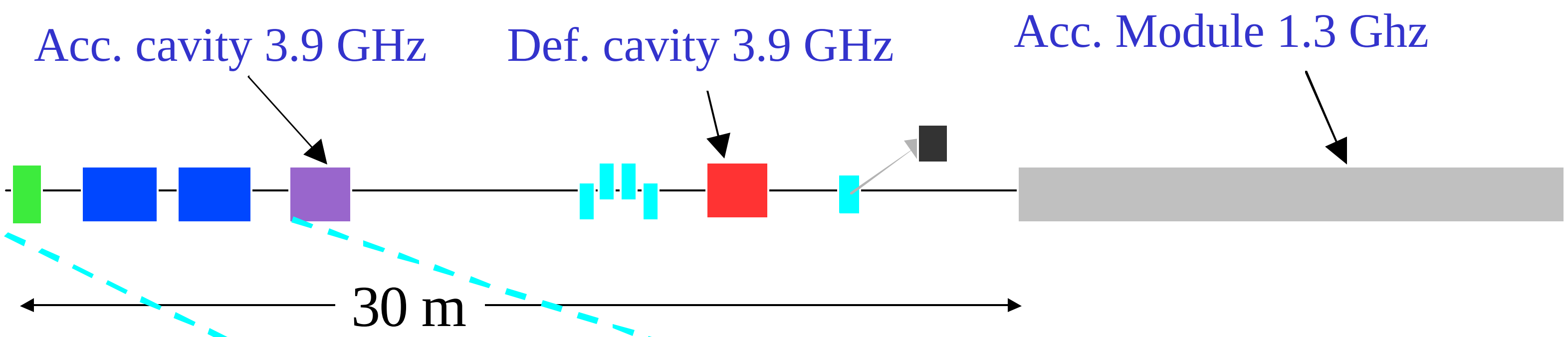
- w/o 3rd harm section (w long cathode laser) BC is nonlinear
- Can get σ_t close to ILC specs

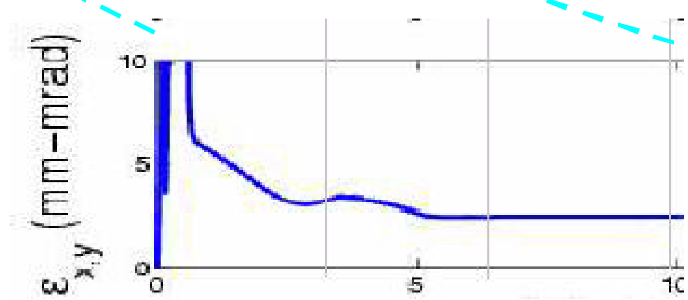
FNPL upgrade @ A0: cavities tests

- Do beam-based (HOM-based) alignment of cap cav 2
- Ideally would like to install both 3.9 GHz cavities in FNPL; but can do relevant tests for each cavity
  - Test of bunch length measurement using TM_{110} cavity located downstream BC
  - Test of TM_{010} cavity ⇨ demonstrate flattening of the rf-potential by observing reduction of energy spectrum
- Improvement/development on LLRF system

Overview of FNPL @ SMTF

- Re-locate FNPL at SMTF location
- re-optimize distance between rf-gun and 1st cavity
- integrate both 3.9 GHz cavities in the accelerator (if proper HOM-damping possible for deflecting cavity)





Assumed a flat-top photo-cathode laser
Q=3.2 nC
2.5 mm-mrad

Injector for SMTF: needed upgrades

- RF and beam pulse length
  - Presently do not need long bunch trains for experiments
  - Gun limited to ~200 μs (breakdown at coupling slot)
  - Modulator limited to 600 μs
    ⇨ upgrade both gun and modulator for long pulses and 5Hz operation
- Photocathode laser stability presently being improved (new diode-pumped osc.); amplification stages need upgrading too
- Bunch spacing can be decreased to 337 ns with new LLRF oscillator + minor change on photocathode laser
- ILC-like parameter:
  - bunch length ⇨ better when 3rd harmonic section installed
  - Round beam emittance meet requirement for ILC DR at 3.2 nC
  - Flat beam can achieve low emittance in one plane ~0.4 mm-mrad (presently) ⇨ expected to improve at higher energy
  - Transverse deflecting cavity can be used as a longitudinal phase space diagnostics

Current plans for FNPL

- Continue current activities up to early 2006:
  - Further optimizations of flat beams
  - Beam dynamics study of beam parameters for different laser time profiles (uniform vs Gaussian)
  - New diagnostics: OTRI, test of new OTR radiator, TOF measurements, EO-imaging
- Early 2006 install 2nd cavity "cap cav. 2"
  - optimize beam parameters at 40-50 MeV
  - HOM measurements?
  - Laser acceleration experiment in user area?
- Later in 2006/2007:
  - Modify bunch compressor
  - install def. cavity (need 3.9 GHz rf-system integrated)